# Inverse modeling of the source term

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# The FLEXPART model

Model descriptions in Atmospheric Environment,
Boundary Layer Meteorology, Atmospheric Chemistry and Physics,
Geoscientific Model Development

Lagrangian particle dispersion model

Turbulence and convection parameterizations

Dry and wet deposition

Inverse modeling

Data input from ECMWF, GFS, MM5, WRF,…

Used at >100 institutes

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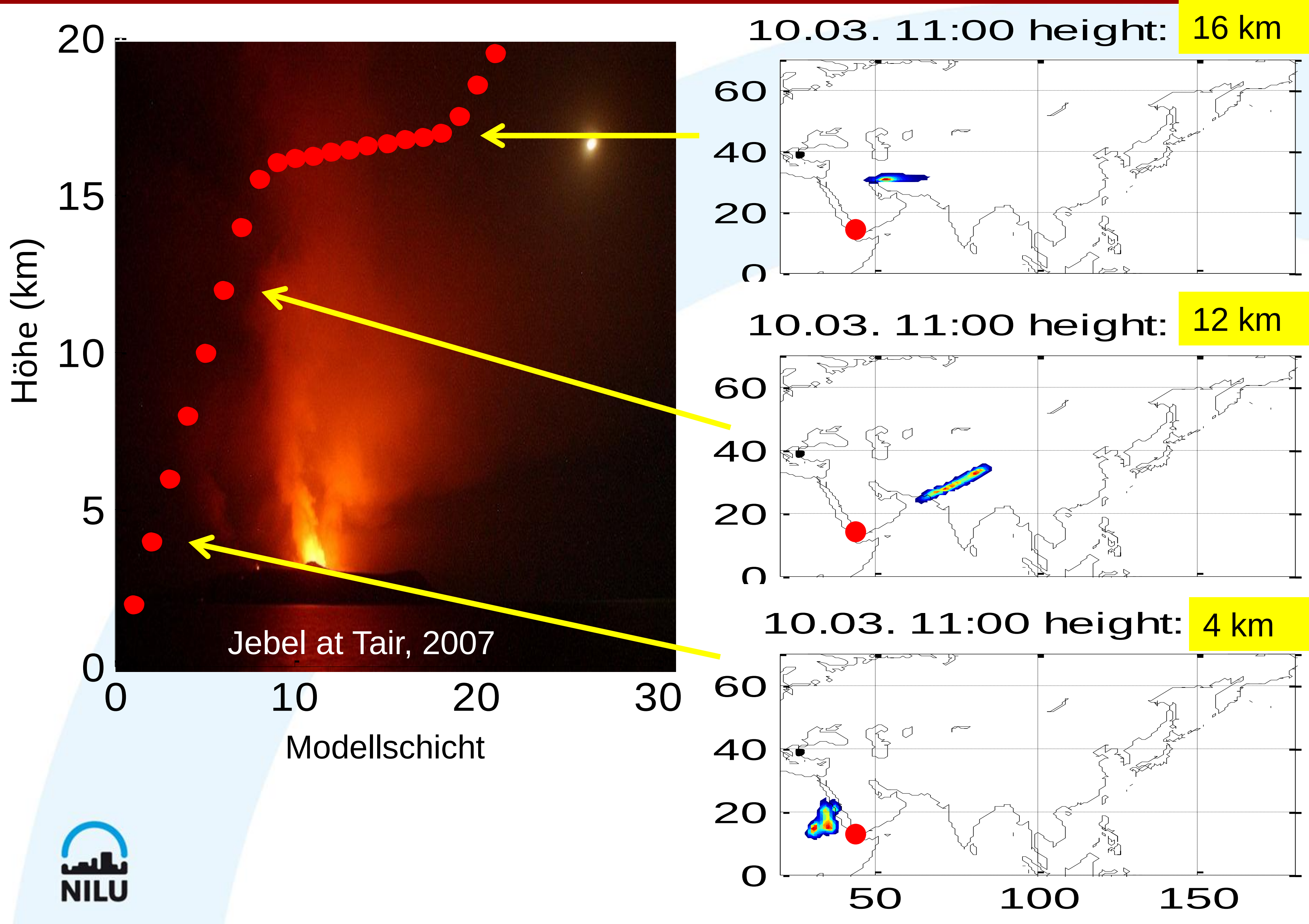
# Transport in atmosphere depends on height of eruption



# Bayesian inversion

Aim: Determination of the emission sources from air concentration measurements

$$M\tilde{x} \approx \tilde{y}.$$

**M** ... *M* x *N* matrix of emission sensitivities from transport model calculations
… often called source-receptor relationship
*x* ... Emission vector (*N* emission values)
*y* ... Observation vector (*M* observations)

Difficulty: poorly constrained problem; large spurious emissions possible as there is no penalty to unrealistic emissions

Solution: Tikhonov regularization: $||x||^2$ is small, use of a priori information

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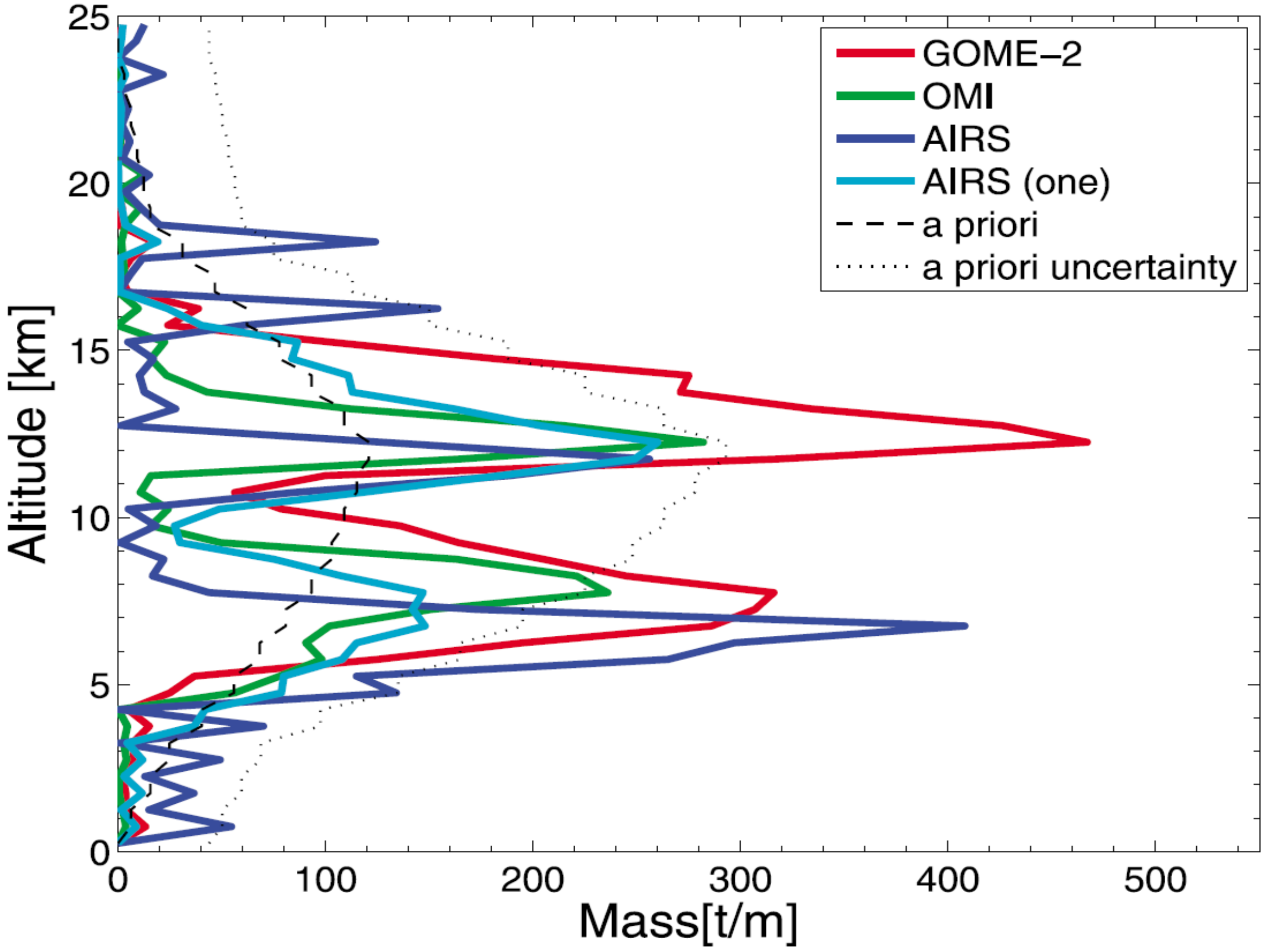
# Kasatochi eruption, 8 August 2008

Kristiansen et al. (2010)

Aleutian island volcano, 3 eruptions within 6 hours

Vertical profiles determined by inverse modeling of $SO_2$ satellite measurements during first two days



# Kasatochi eruption, 2008: Model evaluation with satellite lidar data (CALIOP)

Kristiansen et al. (2010)

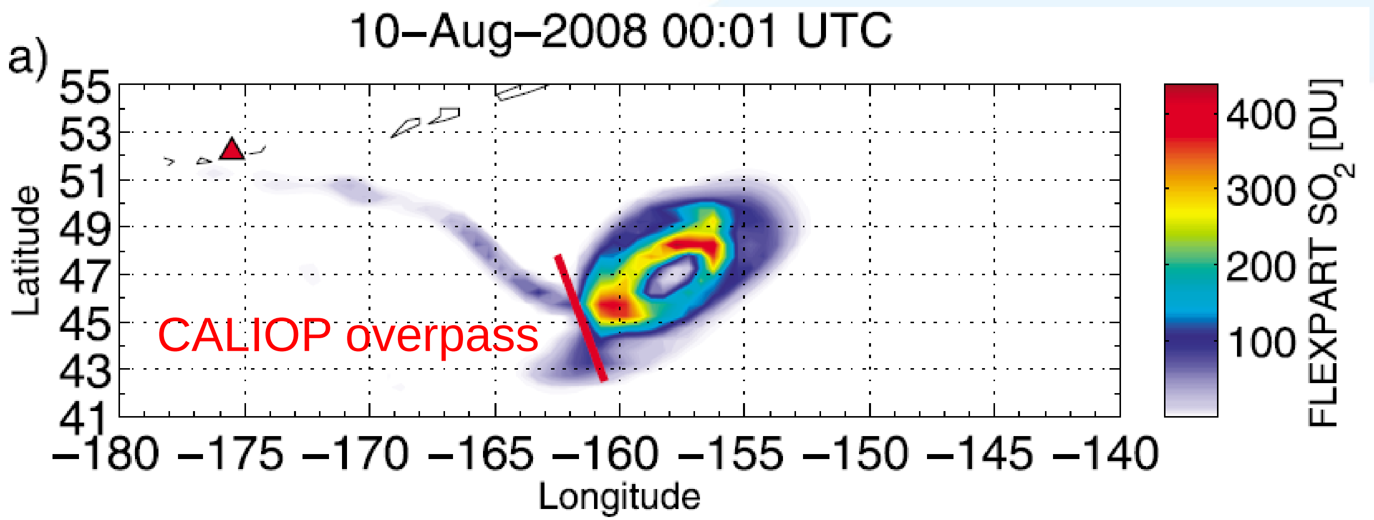
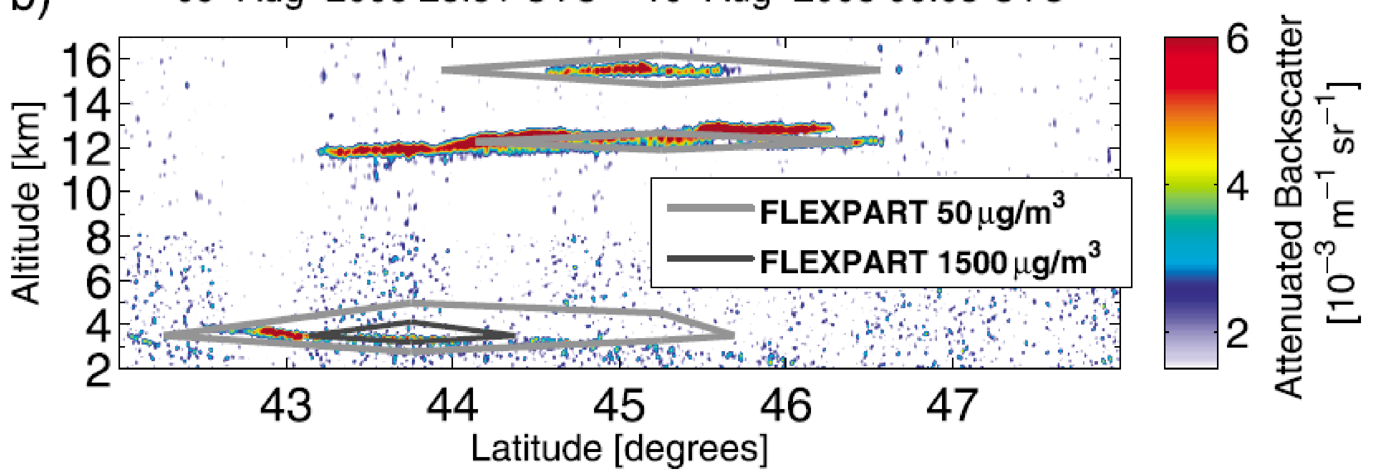


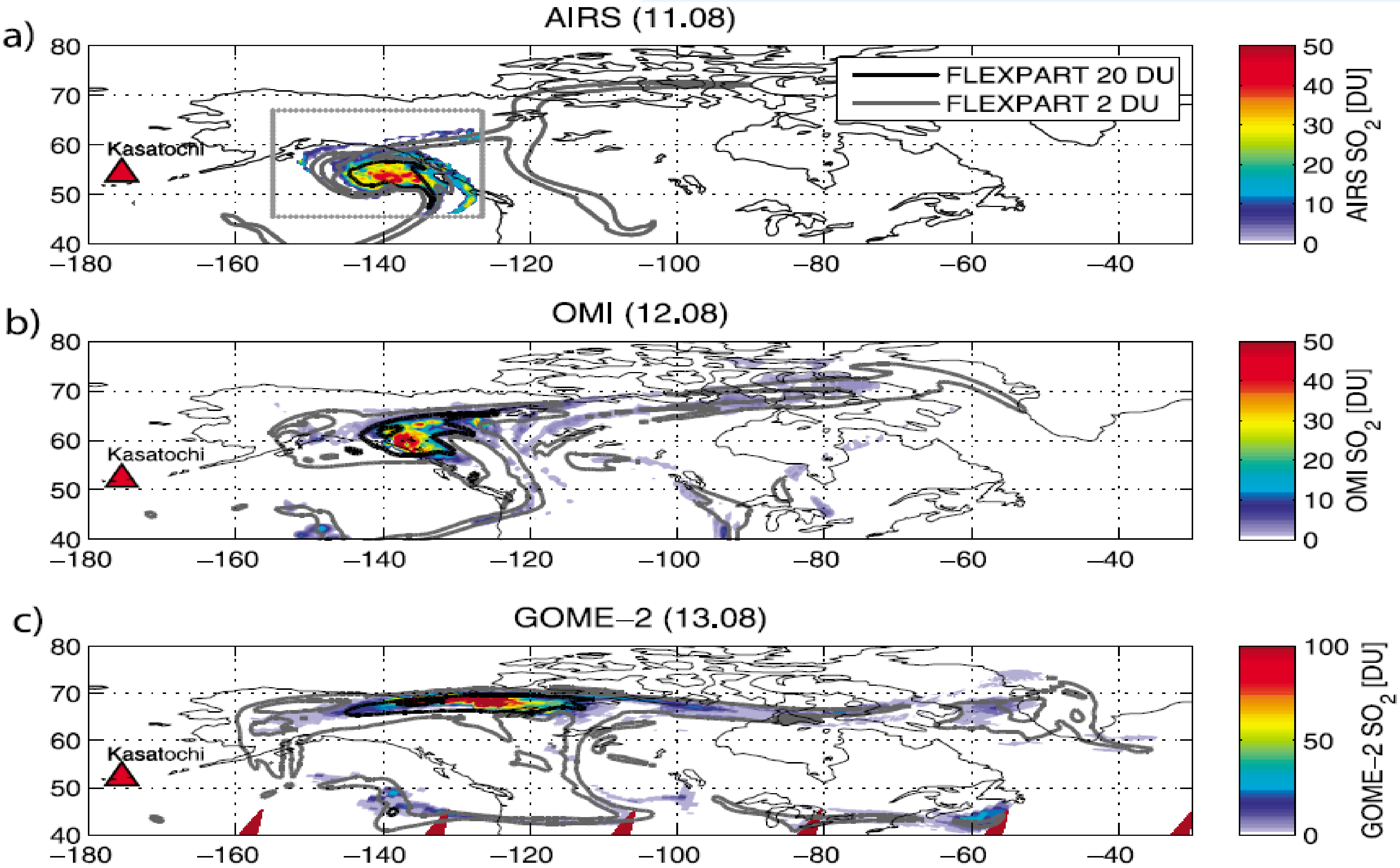

Chart showing simulated $SO_2$ column concentrations




CALIOP: Lidar measurements along red line in (a)

# Kasatochi eruption, 2008: Model evaluation

Kristiansen et al. (2010)



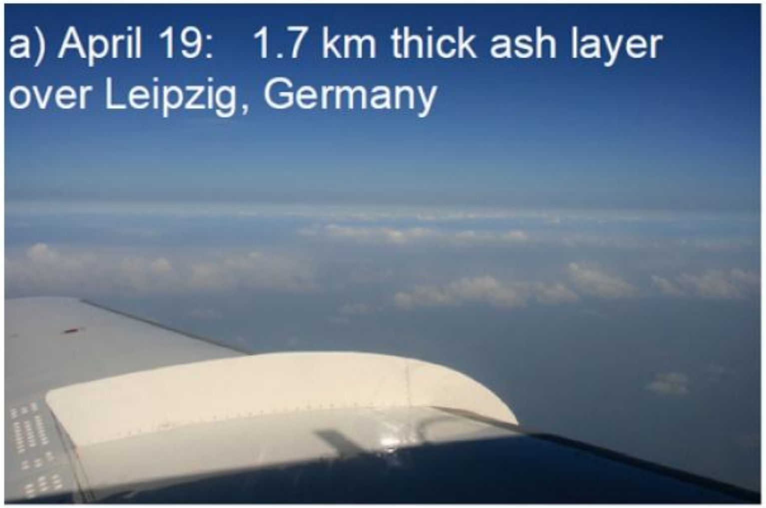
# Eruption of Eyjafjallajökull, 2010

Stohl et al. (2011), Kristiansen et al. (2012)

Opportunity to apply our algorithm to volcanic ash

Use of SEVIRI and IASI IR-Retrievals (Ash total columns)

Challenge: Ash emissions had to be determined as a function of height <u>and</u> time




# A priori emissions

1. VAAC plume height reports, 3-hourly radar data

2. Forced PLUMERIA 1-D model (Mastin, 2007) to reproduce plume heights, using 3-hourly vertical profiles of actual meteorological data

3. Assumed that 10% of the ash mass flux was in the observed size range (2.8-28 µm): total of 11.4 Tg

# Model simulations

Based alternatively on ECMWF (0.18 deg resolution) and GFS (0.5 deg) meteorological input data

Difference used to quantify model error

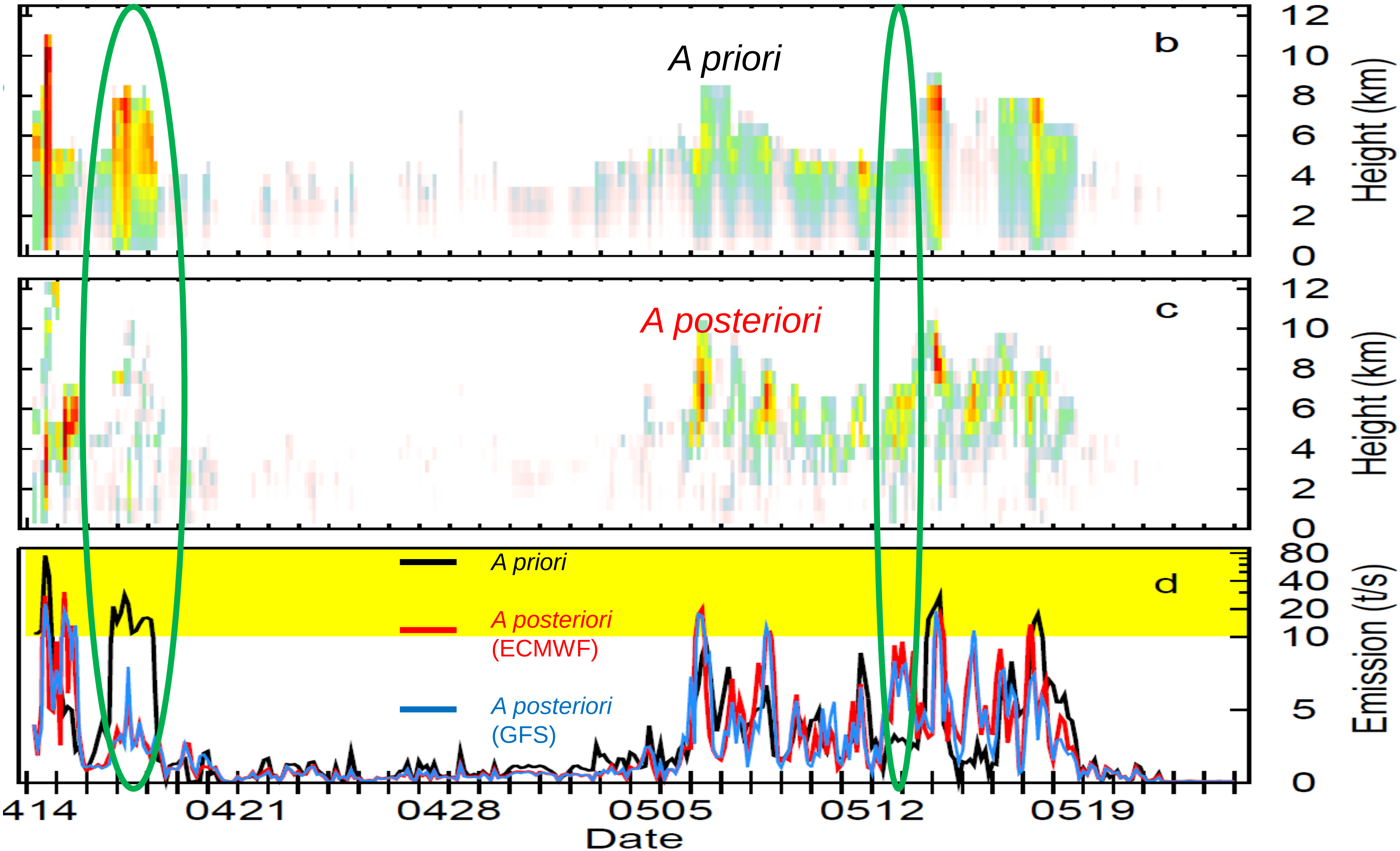
6232 forward model simulations used as input for inversion: 19 height levels a 650 m, 328 times (3-hour resolution), output resolution 0.25 deg

Ash column loadings based on infrared retrievals from SEVIRI (geostationary) and IASI (polar orbiting) were used: 2.3 million observations in total

SEVIRI data were used at 0.25 deg resolution every hour

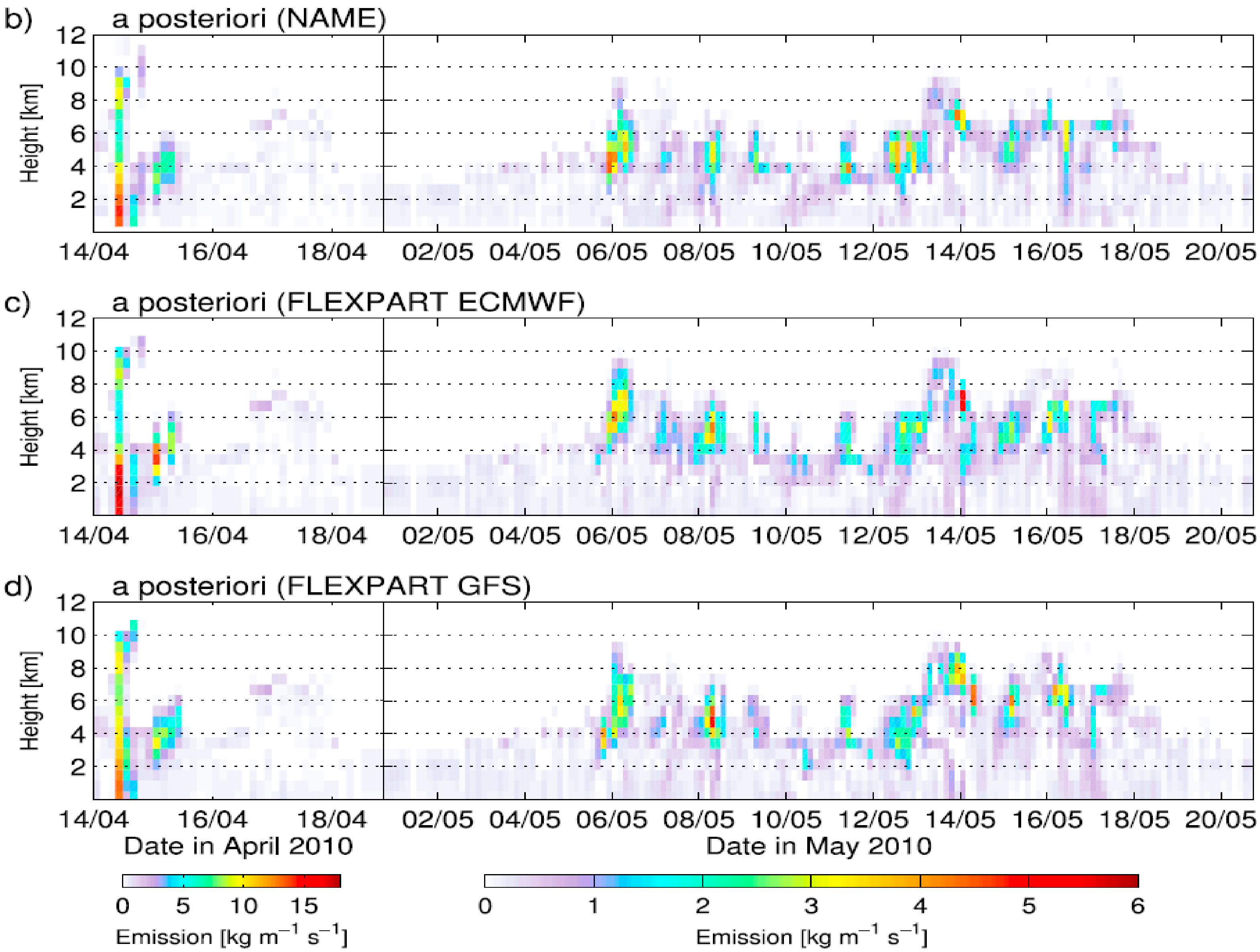
# Ash emissions as a function of height and time

Stohl et al. (2011)



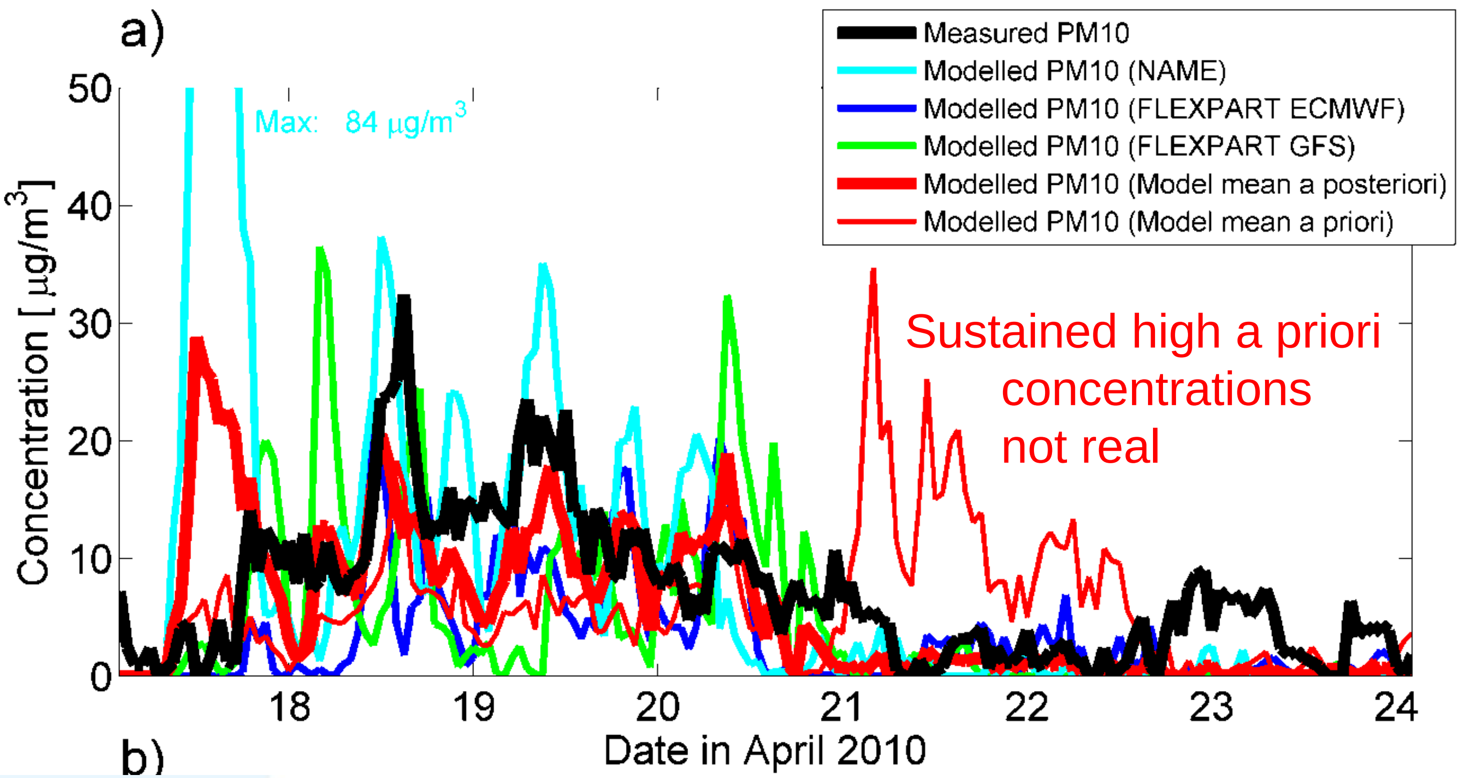
# Derived source term not very model-dependent

(Kristiansen et al., 2012)

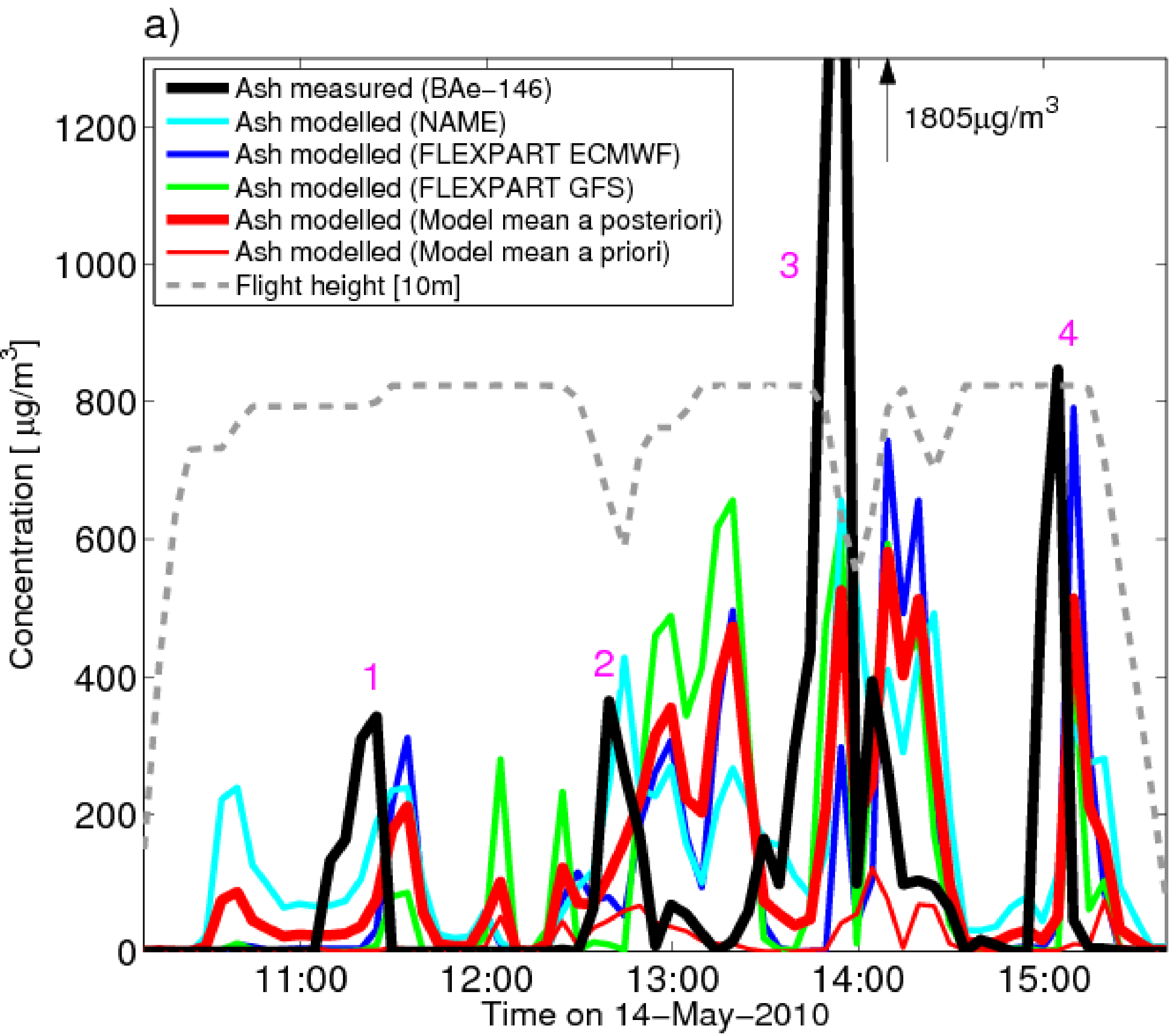


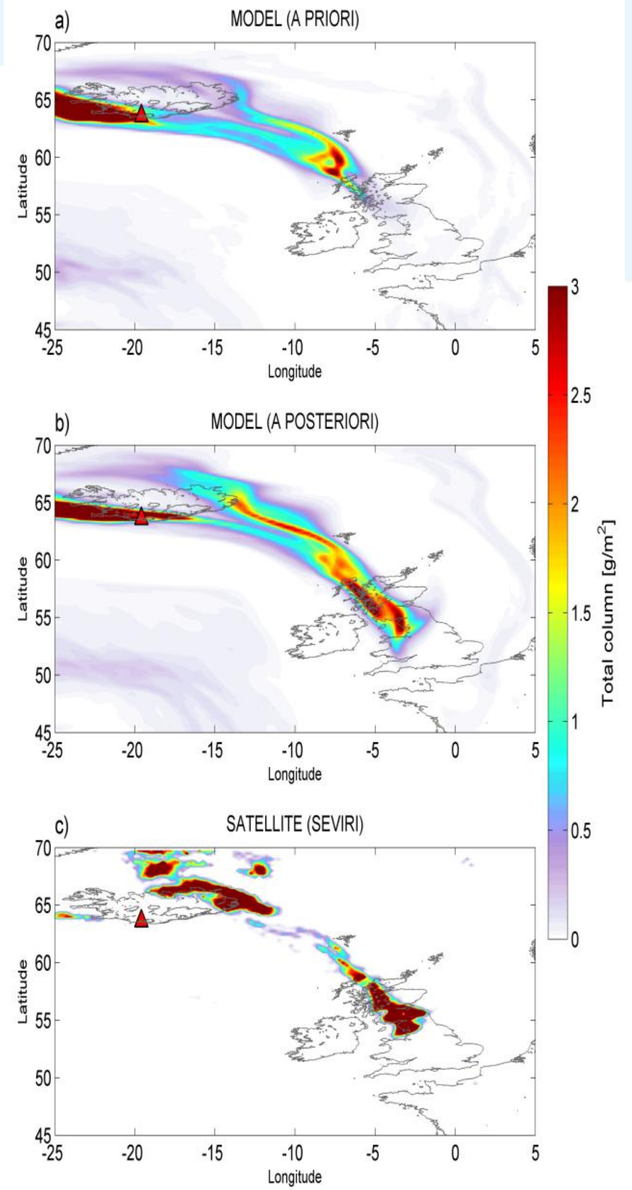
# Comparison of 3 models vs. Jungfraujoch station measurements

(Kristiansen et al., 2012)



# Comparison of 3 models vs. Bae-146 measurement flight on 14 May (Kristiansen et al., JGR)



# Comparison with airborne measurements (Falcon, Bae-146, DIMO) and Jungfraujoch data

Statistical comparison of all ash plumes measured by three research aircraft, and at Jungfraujoch station, with model

Modeled values are mean of ensemble (FLEXPART-ECMWF, FLEXPART-GFS and NAME)

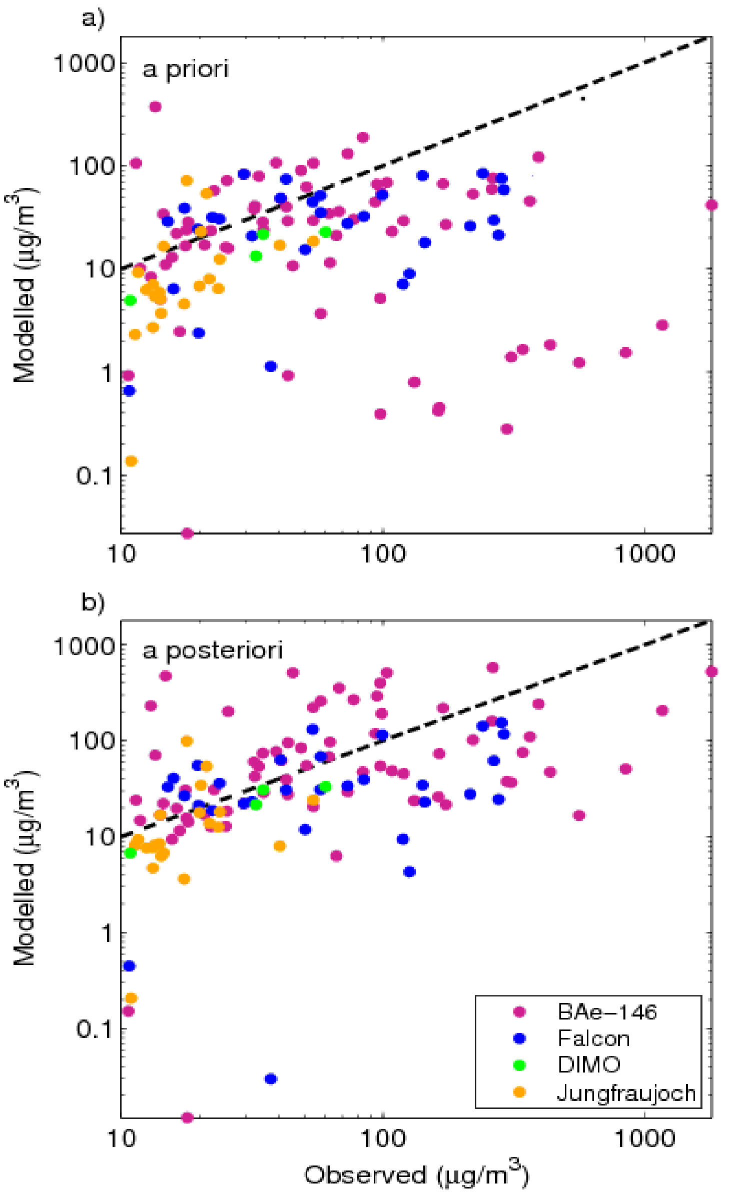
**A posteriori clearly better than a priori:**

Rank correlation improves from 0.21 to 0.55

Pearson correlation improves from -0.02 to 0.36

Bias is reduced from -78 to -32 µg/m³

**Uniform height distribution totally uncorrelated (not shown)**

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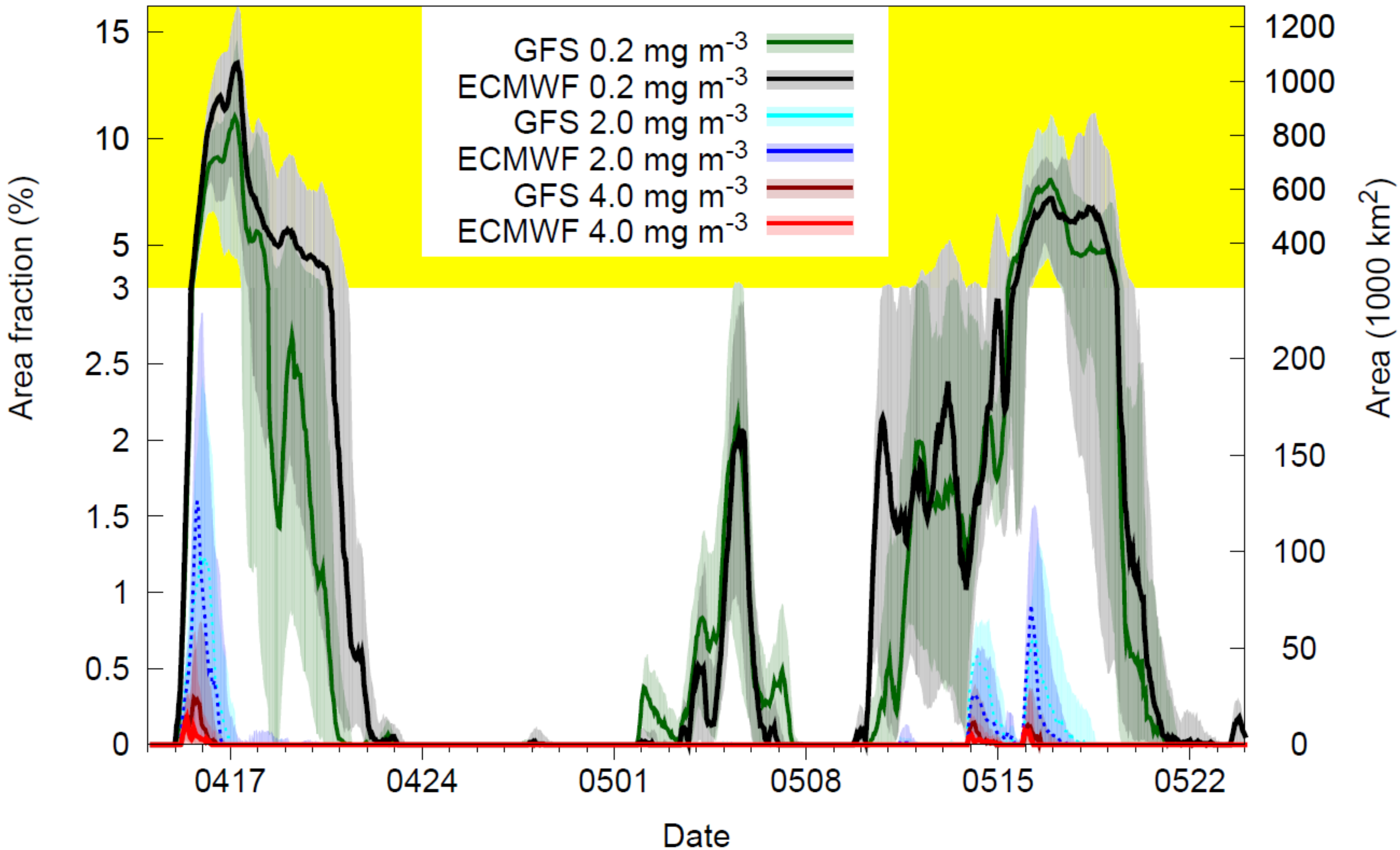
# Area over Europe that was affected by ash above certain thresholds (somewhere in the vertical)



# Eruption of Grimsvötn in May 2011

Moxnes et al., submitted to J. Geophys. Res.

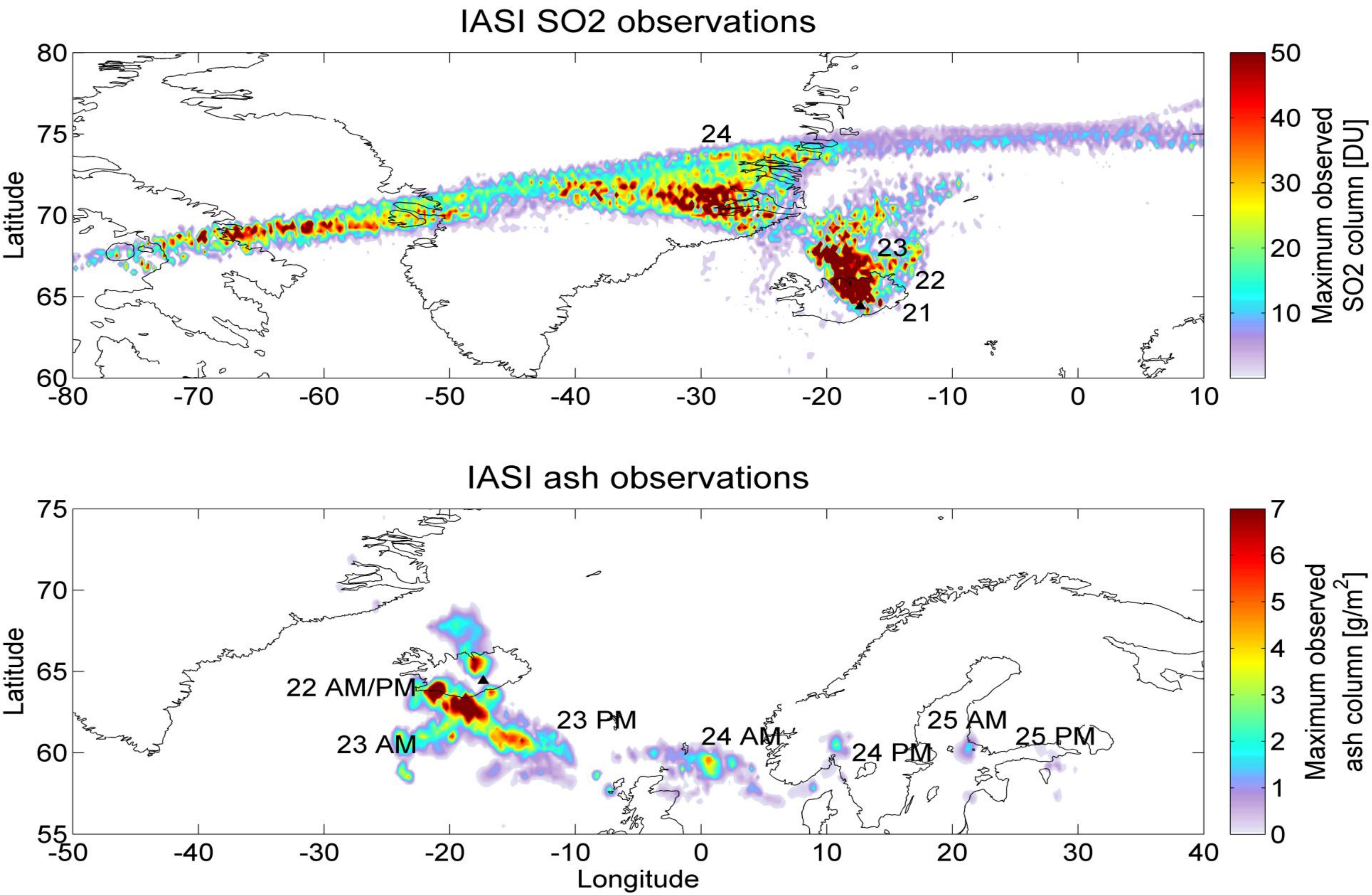
Again, disruption to air traffic but not as severe as for the Eyjafjallajökull eruption

Ash- and sulfur-rich eruption

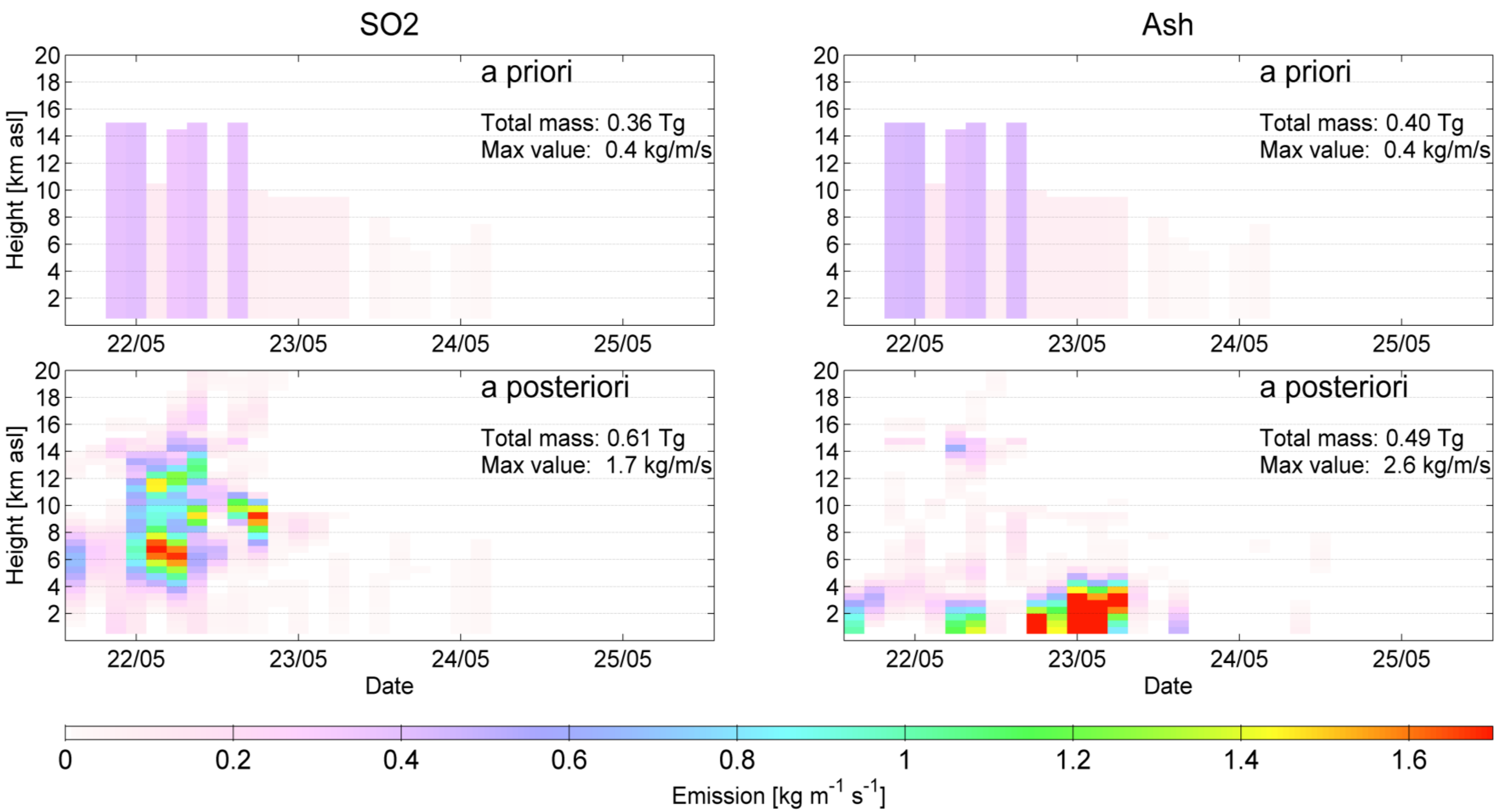
Performed inversions for ash and $SO_2$ to investigate differences in emission height/time

Input data: IASI satellite retrievals for ash and $SO_2$

# Different transport routes seen from IASI satellite instrument

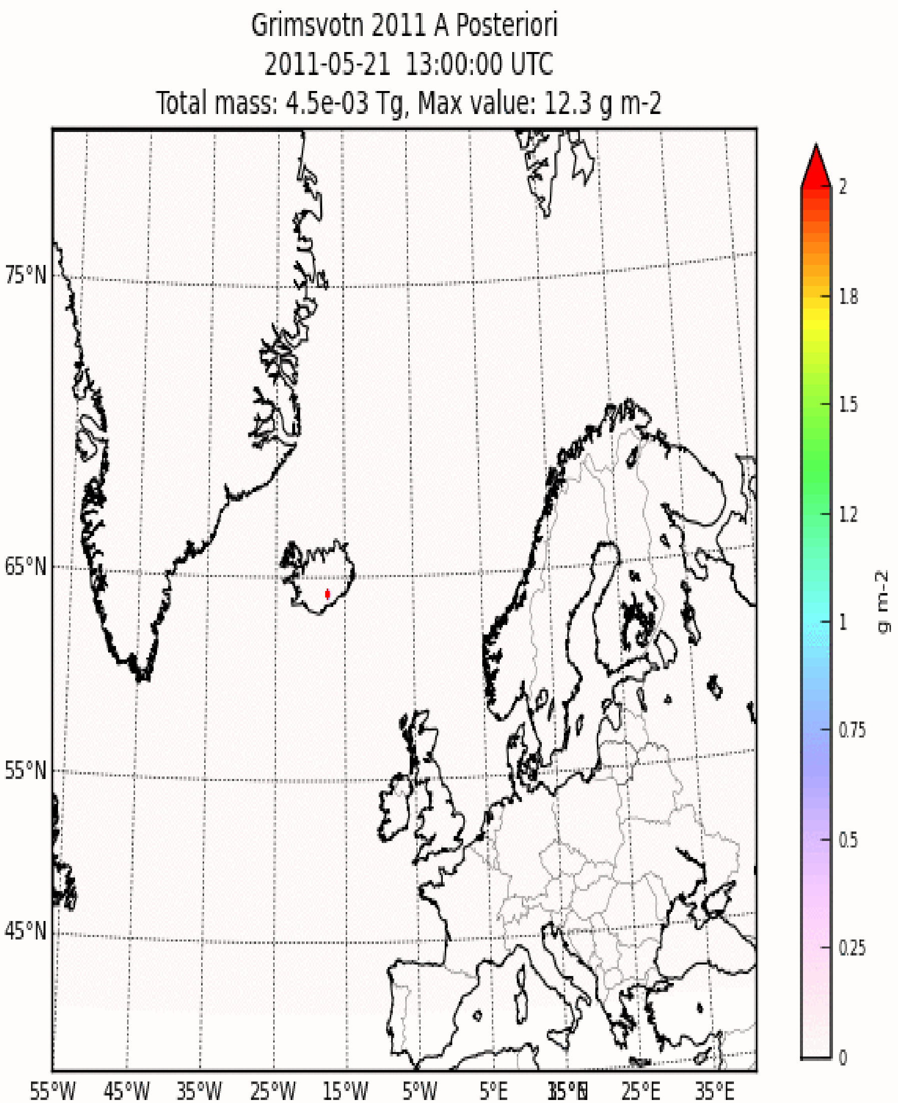


# Source terms noisy, but $SO_2$ was injected high, ash was injected low

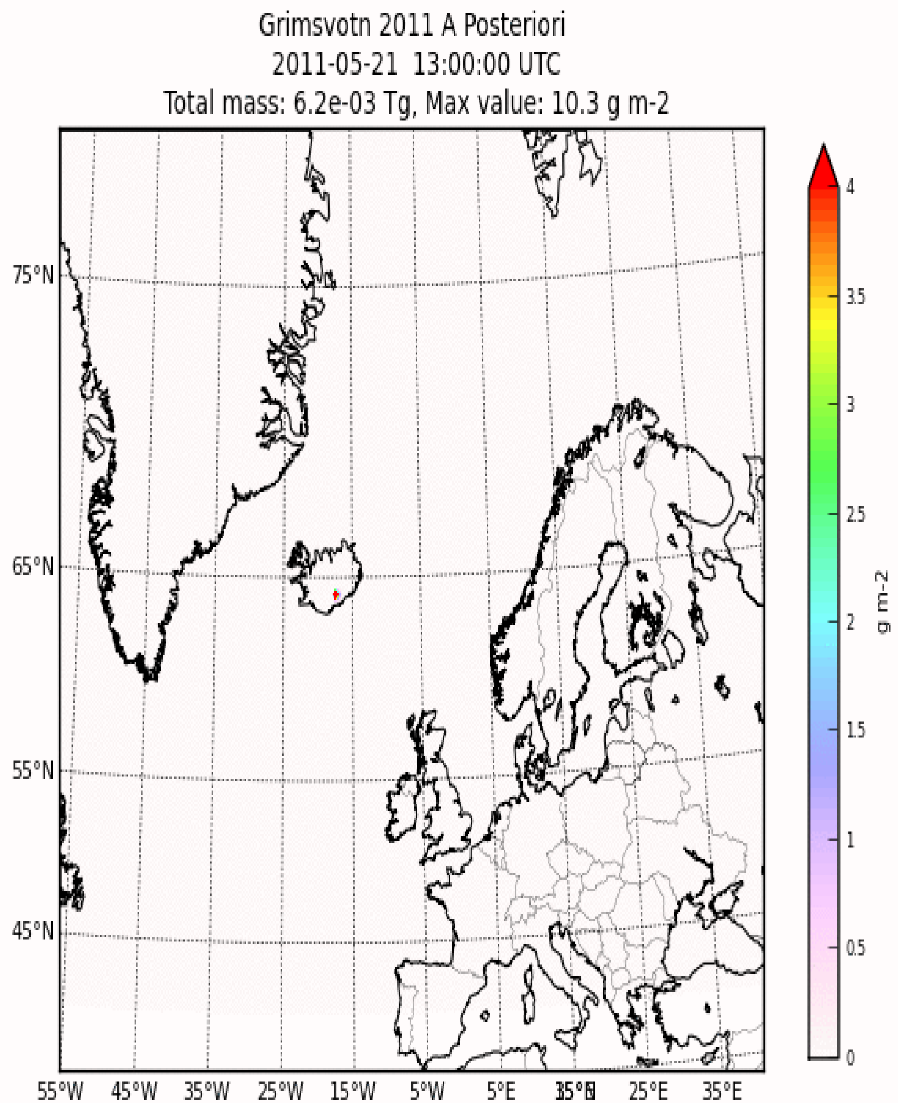


# Simulated transport of ash and $SO_2$

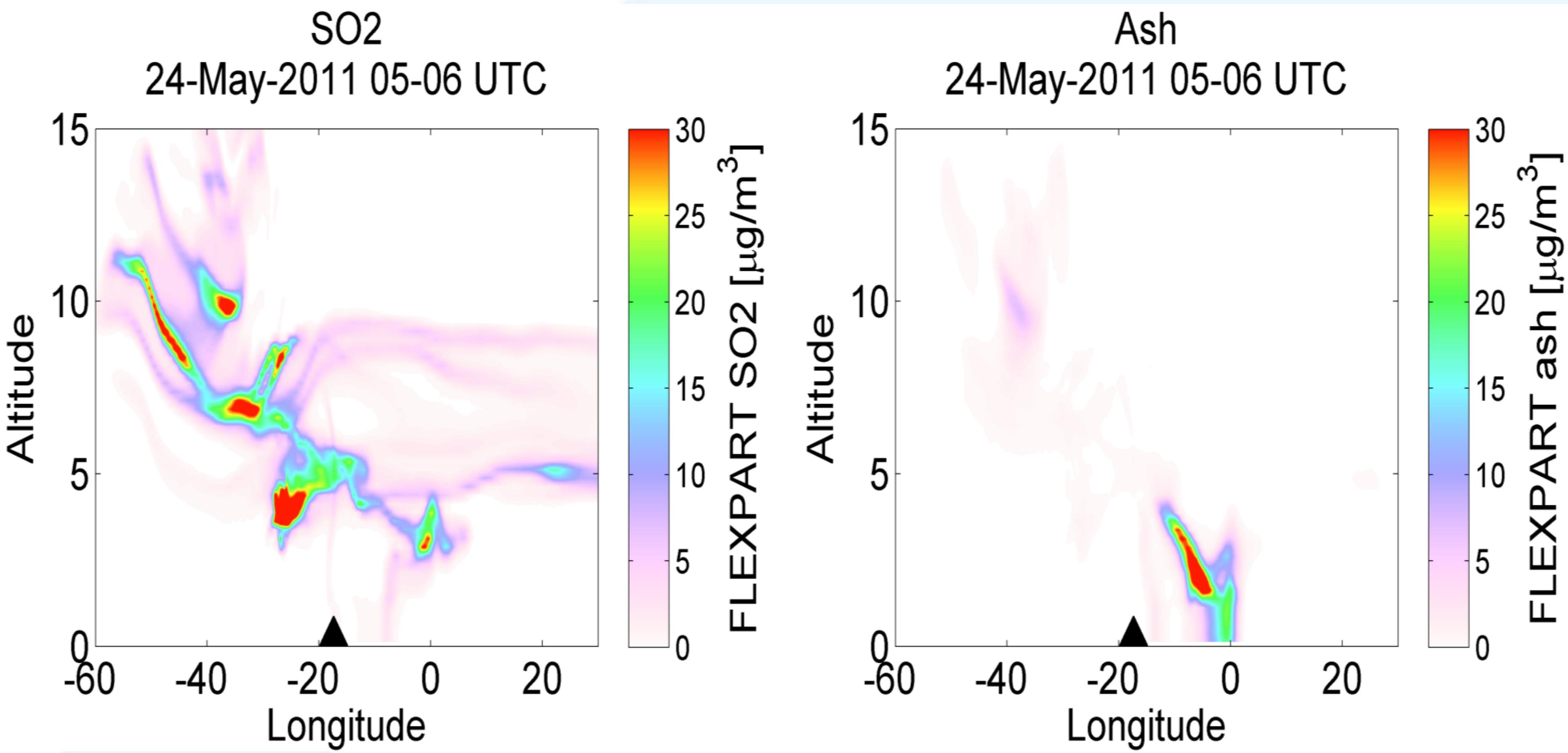
FLEXPART ASH




FLEXPART $SO_2$



# Vertical section through model output



# Validation of modeled $SO_2$ with independent satellite data (SCIAMACHY and GOME)

| Figure 8 | SCIAMACHY | FLEXPART (A POST) | FLEXPART (A PRIORI) |
|---|---|---|---|
| Mean | 19.8 | 21.7 | 11.0 |
| Bias | | 2.0 | -8.8 |
| NMSE | | 0.7 | 3.1 |
| FOEX | | -11.1 | -22.1 |
| PCC conf.int. | | 0.69 – 0.80 | 0.19 - 0.41 |
| **Figure 9** | **GOME-2** | **FLEXPART (A POST)** | **FLEXPART (A PRIORI)** |
| Mean | 9.3 | 9.6 | 5.0 |
| Bias | | 0.3 | -4.3 |
| NMSE | | 1.2 | 3.0 |
| FOEX | | 0.2 | -18.0 |
| PCC conf.int. | | 0.37 – 0.58 | 0.13 – 0.38 |

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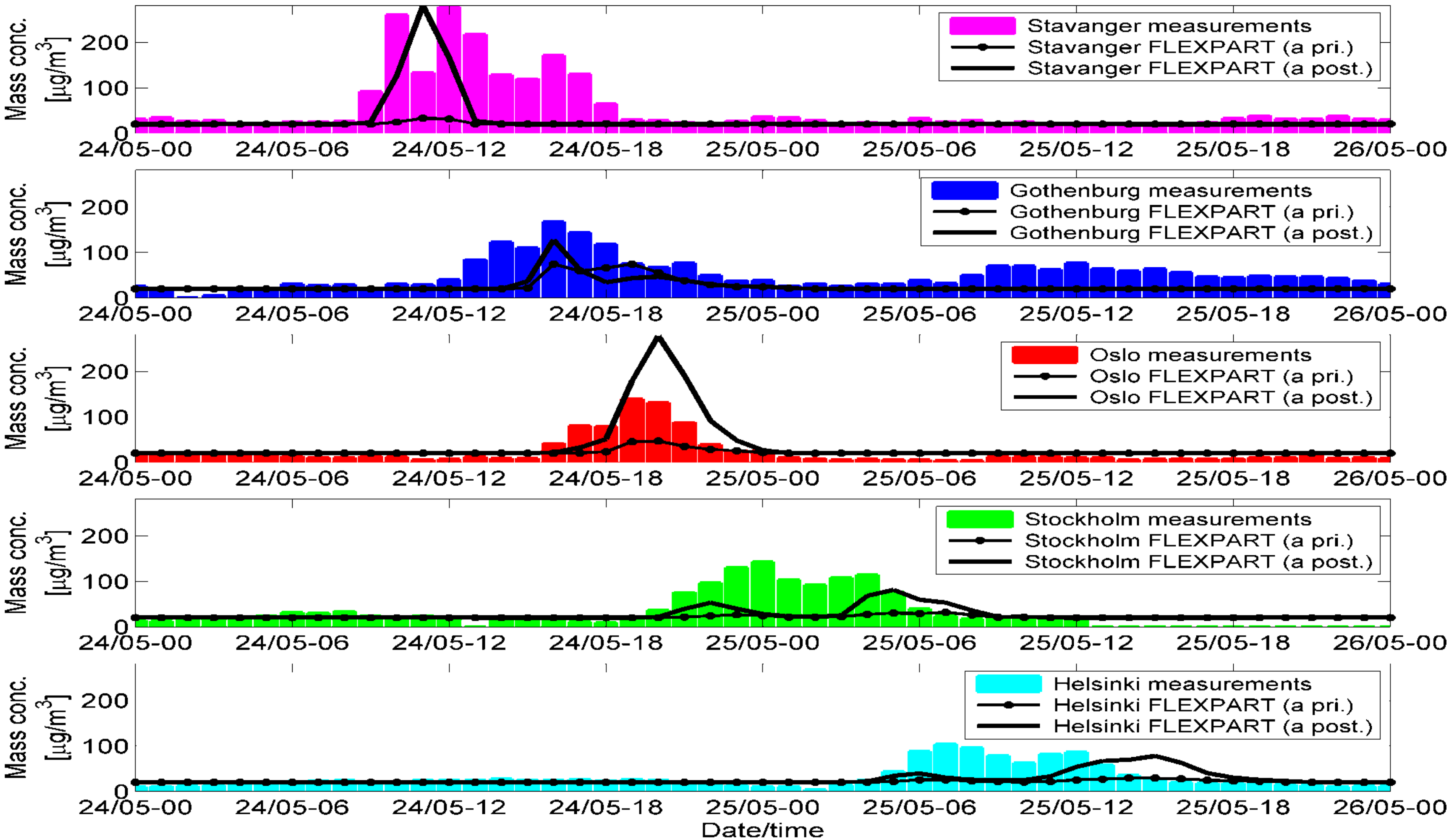
# Comparison of simulated ash to ground-based air quality measurements in Scandinavia




Thank you!